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TWISTEX 2008: IN SITU AND MOBILE MESONET OBSERVATIONS OF TORNADOES

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1. INTRODUCTION

The primary objective of the Tactical Weather Instrumented Sampling in/near Tornadoes Experiment (TWISTEX) in 2008 was to collect thermodynamic and kinematic datasets near tornadic circulations using in situ and mobile mesonet instrumentation. With these datasets, improved understanding of low-level tornadic features as well as tornadogenesis and longevity can be achieved.

In May 2008, the TWISTEX field campaign collected four datasets both in and near tornadic circulations. Three of these intercepts were unintentionally sampled, as these circulations were displaced from visual location of the intense, low-level mesocyclone. The remaining intercept was conducted as planned on a mature tornado.

This study presents background on the instrumentation as well as preliminary results from the data obtained. In addition, comparisons are made to pressure and wind velocity information acquired from laboratory and numerically simulated vortices.

2. METHODS

To accomplish the primary objective of the field campaign, a suite of instruments was deployed in and near the tornadic circulations intercepted. These included both in situ and mobile instrumentation arrays, which are described in the following sections. Additionally, some background on the laboratory and numerically simulated tornadoes is provided.

2.1 *In Situ Instrumentation*

Two types of in situ instrumentation were deployed for the first May 29th case, which included two Hardened In situ Tornado Pressure Recorder (HITPR) probes (Fig. 1a) and one photogrammetric probe (Fig. 1b). Both probes are aerodynamically shaped and engineered to withstand the harsh tornadic environment (Samaras, 2004).

The HITPR probes were outfitted with sensors that measure temperature, pressure, and relative humidity, which are recorded at 10 samples per second. All data underwent quality control inspection.

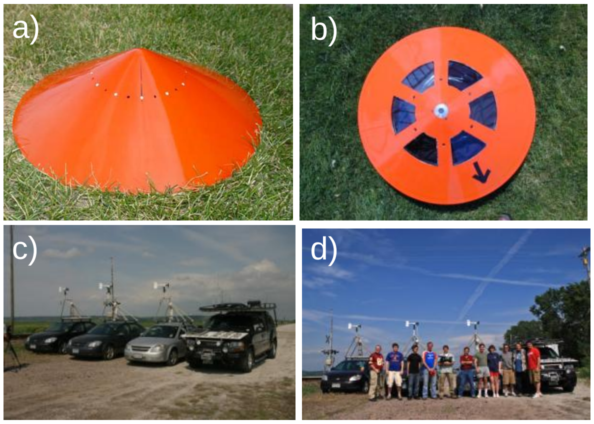

Figure 1. a) HITPR probe b) photogrammetric probe, c) mobile mesonet stations, and d) TWISTEX personnel.

The photogrammetric probe was outfitted with seven cameras to provide visual confirmation of the HITPRs' measurements. Six cameras are positioned horizontally, each spanning a sixty degree horizontal view. These provide a full 360° field of view. The seventh camera is positioned vertically.

2.2 *Mobile Mesonet Stations*

Three vehicles were outfitted with instrumentation to measure temperature, relative humidity, pressure, and wind velocity (Straka et al., 1996), as well as GPS information on position and movement (Fig. 1c and 1d). Once again, all data underwent quality control inspection. When deployed in the hook echo and/or rear flank downdraft (RFD) region of a supercellular storm, these data can provide essential thermodynamic and kinematic information on the environment near a tornado or tornadogenesis region (Markowski et al., 2002).

In light of our primary objective, our goal was to position the mobile mesonet stations to sample the RFD outflow and RFD gust front regions of tornadic supercells. This was successfully achieved on multiple occasions during the project (Finley and Lee, 2008; Lee et al., 2008). However, the mobile mesonet stations also unintentionally intercepted tornadic circulations on three other occasions. Given the remarkable rarity of tornado encounters with research caliber measuring equipment, we felt the scientific significance of these data justified its formal presentation.

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2.3 *Labratory Vortex Simulations*

Iowa State University's Wind Simulation and Testing (WiST) laboratory houses a translating tornado simulator used for modeling purposes. Details regarding the design, construction, and implementation of the simulator can be found in Haan et al. (2008).

Figure 2 shows profiles of pressure obtained from the simulator near the surface, which are normalized by the following equation:

$$Cp = \frac{p - p_\infty}{\frac{1}{2}\rho V^2_{\theta max}}$$

The pressure coefficient (Cp) normalizes the measured pressure (p) and the ambient static pressure (p_∞) with the dynamic pressure ($1/2\rho V^2_{\theta max}$). The horizontal axis normalizes the distance from the vortex center (R) by the radius of the maximum tangential wind speed ($V_{\theta max}$), also called the core radius (Rc).

Profiles of the surface pressure coefficient in Fig. 2 show a large pressure deficit coincident with the center of the vortex in each simulation. The flattening of the profile associated with the medium and large core radius is due to a central downdraft at the vortex axis, the result of increasing swirl ratio and a transition from a one-celled to two-celled vortex structure (Haan et al., 2008). These results are consistent with prior laboratory studies of vortex structure (Church and Snow, 1993).

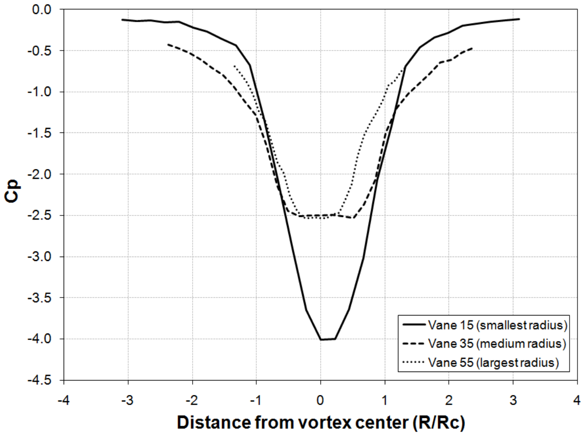

Figure 2. Normalized pressure profiles obtained from three laboratory simulations of varying vortex core radii.

2.4 *Numerical Tornado Simulation*

A numerical simulation of a tornado-like vortex was conducted to allow additional comparison to the laboratory and observational datasets. This simulation was done using Fluent, a computational fluid dynamics (CFD) solver. Details regarding the construction and implementation of the simulation can be found in Le et al. (2008).

Figure 3a shows horizontal profiles of pressure and wind speed through the center of the simulated tornado near the surface. While Cp has less magnitude compared to the laboratory vortex it does show a similar orientation to the medium and largest core radius profiles (Fig. 2), indicating a central downdraft is present at the vortex axis. Further analysis of the dataset confirms this assessment, demonstrating agreement with the aforementioned laboratory studies of vortex structure. Additionally, these results are consistent with prior numerical studies of vortex structure, as shown in Lewellen (1993) and Le et al. (2008).

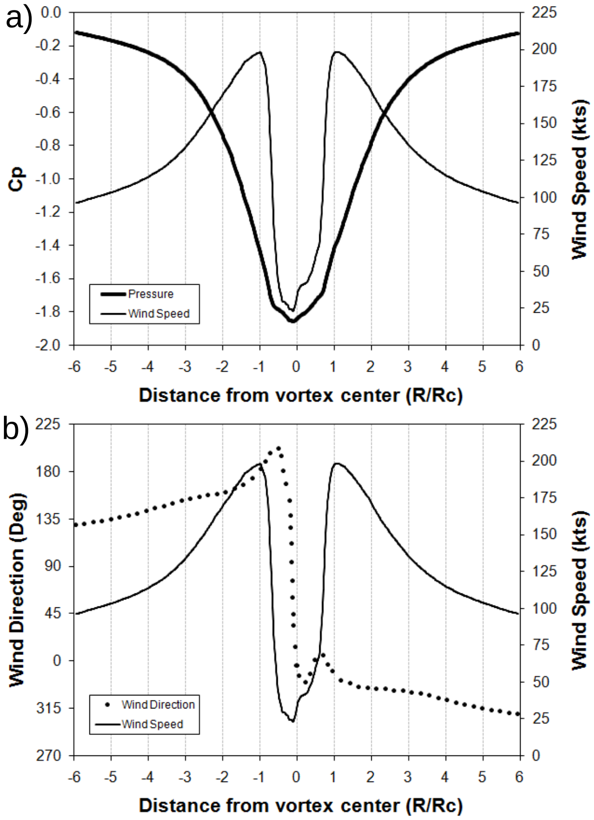

Figure 3. Horizontal profiles of a) normalized pressure (Cp) and wind speed (kts), and b) wind direction (deg) and wind speed (kts).

Figure 3b shows the horizontal profiles of wind speed and direction. A cyclonic circulation is evident with winds shifting from south-southeasterly on the upstream ($-R/R_c$) side of the vortex to north-northwesterly on the downstream ($+R/R_c$) side. Additionally, a drastic shift in the direction occurs in the region classified as the tornado core (-1 to 1).

3. CASES & RESULTS

Tornadic circulations were intercepted on four occasions during the month of May. These dates include May 10th, 23rd, and twice on the 29th. Background and discussion from these events are described in detail in the following sections. In addition, comparisons are made between the observations and the simulations where possible.

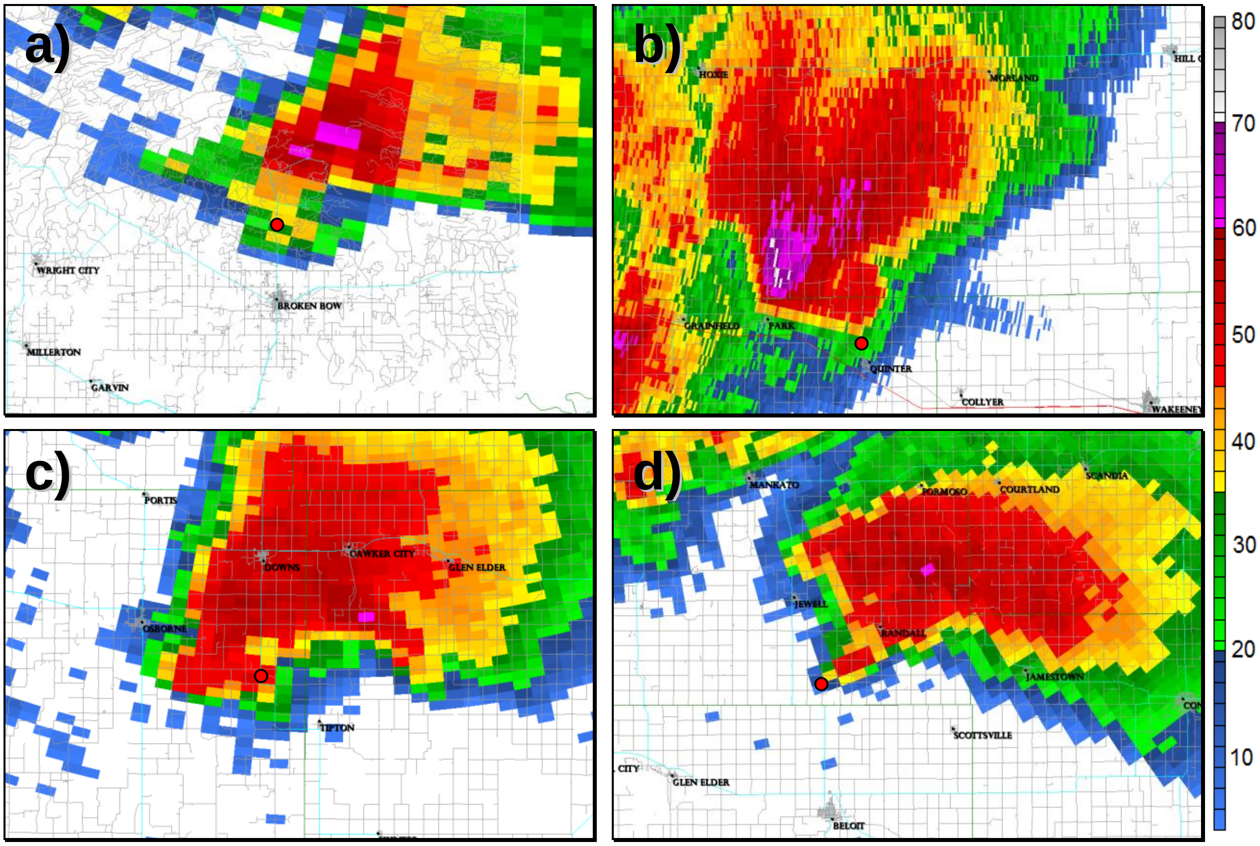

Figure 4. Location of intercepted circulation (red dot) relative to the NEXRAD radar-indicated storm, base reflectivity (dbz), for a) May 10th at 00:33 UTC, b) May 23rd at 21:45 UTC, c) May 29th case 1 at 01:22 UTC and d) May 29th case 2 at 02:17 UTC.

3.1 *May 10th, 2008*

The TWISTEX team intercepted a tornado warned supercell four miles north of Broken Bow, OK at approximately 00:33 UTC. The crew observed the storm as it approached from the northwest, but tornadic features were not particularly evident. As the storm approached, the crew noted that the storm had made a turn to the right, placing them near the path of the mesocyclonic circulation.

The crew drove south on Highway 259 to escape intercepting the mesocyclone. This is where two mobile mesonet stations, M2 and M3, transected a developing tornadic circulation (Fig. 4a). Storm chasers in the area confirmed that a tornado developed on the east side of highway 259.

A pressure drop of approximately 4 mb and a wind gust of 75 kts was measured by M2 (Figs. 5a and 5b). M3 noted a smaller pressure deficit of approximately 2.5 mb, but a substantially higher wind gust near 100 kts. Both wind gusts were observed approximately 10 seconds after measuring the pressure drop. We hypothesize two possible explanations for this occurrence.

First, the mobile mesonet stations may have driven into a developing circulation as evidenced in the recorded pressure deficits, followed by stronger tornadic winds. Second, and potentially more plausible, the circulation transected by the mesonet stations was relatively weak, and as the stations continued to traverse south, they encountered a commencing RFD outflow surge (Finley and Lee, 2004; Lee et al., 2004) which may have been associated with the development of the tornado.

3.2 *May 23rd, 2008*

A tornadic supercell moving nearly due north was intercepted south of Quinter, KS shortly after 21 UTC. The mobile mesonet proceeded north on Castle Rock Road, through the town of Quinter. While sampling the RFD outflow north of Quinter, a tornado was observed approximately 2-3 km to the north, positioned due east of the main storm mesocyclone. Meanwhile, a large tornado quickly formed to the west-northwest of the mesonet. This tornado propagated in a more northeasterly direction, passing within 1 km to the northwest and north of the lead mesonet station (Fig. 4b).

Two mobile mesonet stations, M1 and M2, were positioned rather close to the large tornado and experienced several RFD surges (Finley and Lee, 2008). Both stations recorded pressure drops, with M2

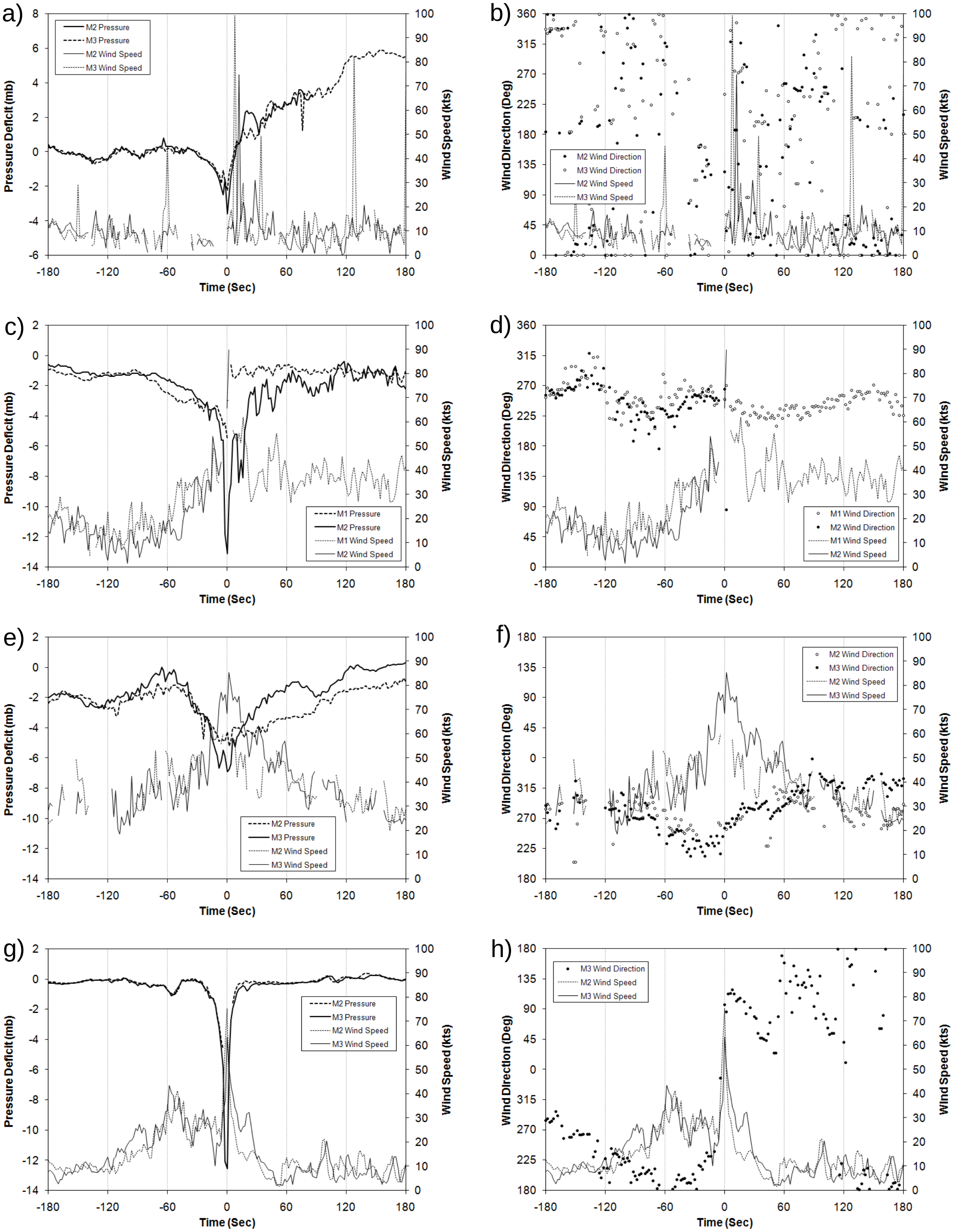

Figure 5. Pressure deficit (mb) and wind speed (kts) versus time for a) May 10th, b) May 23rd, c) May 29th case 1, and d) May 29th case 2, and wind direction (deg) and wind speed (kts) versus time for a) May 10th, b) May 23rd, c) May 29th case 1, and d) May 29th case 2. Figures are normalized to the time of vortex passage (0 sec).

recording the most significant pressure deficit of nearly 12 mb at 21:44 UTC, while M1 had a pressure drop of approximately 4 mb at approximately the same time (Fig. 5c). Immediately following the pressure drop from M2, the pressure trace was rather unsteady for brief period. This was likely associated with small vortices shed from the nearby upstream downed power poles and power lines, or with trauma incurred by the mesonet station during this event.

In addition to the pressure deficits, both mobile mesonet stations recorded significant wind gusts (Fig. 5d) with M2 measuring a 90 knot gust out of 85°. While not quantitatively official due to just missing the vehicle acceleration QC acceptance threshold, M1 recorded a 94 knot gust, at a time concurrent with nearby power poles being blown over. These maximums were coincident with the pressure drops recorded at each station. Winds before and after the time of maximum wind gusts were generally from a westerly direction.

Several chasers were in this area at the time, and reported a narrow satellite vortex passing over/near M2. The pressure and wind speed measurements seem to strongly support this observation.

3.3 *May 29th, 2008 – Case 1*

After parting the initially targeted storms near Kearney, NE, the crew journeyed south and intercepted a tornadic supercell with a developing tornado five miles northwest of Tipton, KS, on Highway 181 at approximately 01:22 UTC (Fig. 4c).

Two mobile mesonet stations, M2 and M3, were positioned near the tornado, with M3 positioned just south of the circulation and M2 about one kilometer south. Furthermore, two HITPR probes (Fig. 1a) and one photogrammetric probe (Fig. 1b) were deployed in the path of the tornado. The probes took a direct hit from the mature tornado.

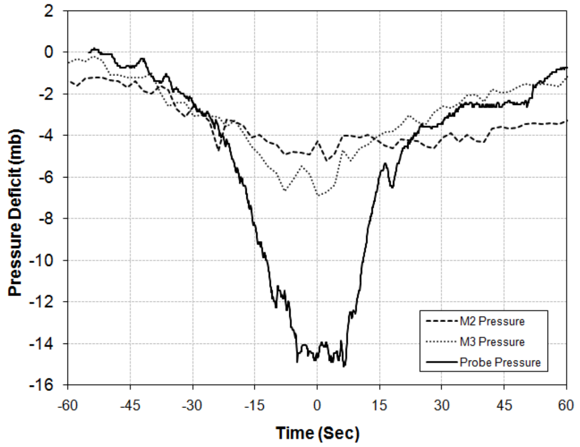

Figure 6. Pressure deficit from M2, M3, and a HITPR probe normalized to tornado passage (0 sec).

Figure 5f shows both mesonet stations recorded sustained winds speeds over 40 knots, with a maximum gust of 86 knots from M3. Additionally, winds shifted from west to southwest just prior to the passage of the tornado at M3's position. After the tornado passed, the winds switched to a northwesterly direction, indicative of a cyclonic circulation moving by just to the north.

The magnitude of the pressure deficit is shown in Figs. 5e and 6 from instrumentation deployed on Hwy. 181. M2 measured the smallest pressure deficit, being positioned farthest from the tornado, while the HITPR probe recorded the largest deficit of about 15 mb. The flattening of the HITPR profile is similar to results from the laboratory (Fig. 2) and numerical (Fig. 3a) simulations, which is suggestive of a two celled vortex structure with an axial downdraft present.

An in depth analysis of the kinematic and thermodynamic structure pertaining to this event can be found in Lee et al. (2008).

3.4 *May 29th, 2008 – Case 2*

About one hour after the first intercept, at approximately 02:17 UTC, the crew intercepted a weak tornadic circulation about eight miles north of Beloit, KS (Fig. 4d). Two mobile mesonet stations, M2 and M3, were positioned facing west, roughly 6 m apart. By this time, the sun had set, and the mesonet had abandoned coordinated data gathering attempts for the evening.

Figure 5g shows M3 measured a pressure drop of nearly 13 mb, coincident with the maximum wind gust of about 75 kts. The pressure sensor on M2 is more sensitive to rapid fluctuations in pressure, and thus was unable to record during this important time period.

Interestingly, Fig. 5h shows the wind direction from M3 switched from westerly to southerly prior to the tornado passage. Then, it rapidly changed to the east before gradually becoming more south-southeasterly. Additionally, the highest wind speeds were out of the east-southeast.

Analysis of video at this time suggests the tornadic circulation propagated from south to north, with the center of the vortex skimming the team to the east. From the above information, we believe the mesonet stations transected an anticyclonic tornado.

4. CONCLUSIONS

From the results presented here, tornadic circulations were intercepted and measured on four occasions. These data add to the very small collection of measurements from in and near tornadoes (Samaras, 2004). In addition, our results show similarities to previously documented measurements of tornadic circulations (Straka et al., 1996; Winn et al., 1999; Samaras, 2004).

In these events, a rapid pressure deficit is nearly coincident with the maximum wind gust. Pressure deficits ranged from 4 to 15 mb, while maximum 3 m wind gusts ranged from 75 to 100 kts. The most significant pressure deficits did not coincide with the largest wind gusts, due likely to pressure gradient, sampling position and sampling interval considerations.

Finally, the general characteristics of the TWISTEX observations compare well with idealized laboratory and numerical simulations. Interestingly, the pressure trace from the May 29th case1 probe dataset (Fig. 6) is very suggestive of a two-celled vortex as shown in both current and prior laboratory and numerical modeling studies. This emphasizes the necessity for high resolution sampling in and near the tornado core to provide ground truth comparative cases.

5. FUTURE WORK

Efforts will continue in future TWISTEX field projects to collect measurements of the tornadic flow field near the surface. This region remains relatively unexplored, and may provide clues to better the understanding of tornadic flow field properties. This information could potentially advise and guide structural engineering interests and could aid in assessing damage potential. New technologies are being developed that will provide improved methods of sampling this mysterious and harsh environment.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Church, C. R., and J. T. Snow, 1993: Laboratory models of tornadoes. *The Tornado: Its Structure, Dynamics, Prediction and Hazards, Geophys. Monogr.,* No. 79, Amer. Geophys Union, 19–39.

Finley, C. A. and B. D. Lee, 2008: Mobile mesonet observations of an intense RFD and multiple RFD gust fronts in the May 23 Quinter, Kansas tornadic supercell during TWISTEX 2008, Preprints, *24th Conference on Severe and Local Storms,* Savannah, GA.

Finley, C. A., and B. D. Lee, 2004: High resolution mobile mesonet observations of RFD surges in the June 9 Basset, Nebraska supercell during project answers 2003. Preprints*, 22nd Conf. on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., Conference CD-ROM,. 11.3.

Haan, Jr., F. L., P. P. Sarkar, and W. A. Gallus, Jr., 2008: Design, construction and performance of a large tornado simulator for wind engineering applications, *Eng. Struct.,* **30,** 1146-1159.

Le, K., F. L. Haan, Jr., W. A. Gallus, Jr., and P. P. Sarkar, 2008: CFD simulations of the flow field of a laboratory-simulated tornado for parameter sensitivity studies and comparison with field measurements, *Wind and Structures,* **11,** 75-96.

Lee, B. D., C. A. Finley, and P. Skinner, 2004: Thermodynamic and kinematic analysis of multiple RFD surges for the 24 June 2003 Manchester, South Dakota cyclic tornadic supercell during Project ANSWERS 2003. Preprints*, 22nd Conf. on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., CD-ROM, 11.2.

Lee, B. D., C. A. Finley and T. M. Samaras, 2008: Thermodynamic and kinematic analysis near and within the Tipton, KS tornado on May 29 during TWISTEX 2008, Preprints, *24th Conference on Severe and Local Storms,* Savannah, GA.

Lewellen, W. S., 1993: Tornado vortex theory. *The Tornado: Its Structure, Dynamics, Prediction and Hazards, Geophys. Monogr.,* No. 79, Amer. Geophys. Union, 19–39.

Markowski, P. A., J. M. Straka, and R. N. Rasmussen, 2002: Direct surface thermodynamic observations within the rear-flank downdrafts of nontornadic and tornadic supercells. *Mon. Wea. Rev.,* **130**, 1692-1721.

Samaras, T. M., 2004: A historical perspective of in-situ observations within tornado cores. Preprints, *22nd Conf. on Severe Local Storms, Hyannis, MA, Amer, Meteor. Soc., CD_ROM,* P11.4.

Straka, J. M., E. N. Rasmussen, and S. E. Fredrickson, 1996: A mobile mesonet for finescale meteorological observations. *J. Atmos. Oceanic Technol.,* **13,** 921–936.

Winn, W. P., S. J. Hunyady, and G. D. Aulich, 1999: Pressure at the ground in a large tornado. *J. Geophys. Res.,* **104D,** 22 067–22 082.